DEVELOPMENT OF AN ULTRALIGHT PULSE GAS METAL ARC WELDING SYSTEM FOR SHIPYARD APPLICATIONS

CNST Task Order 2004-388, Task 1

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GENERAL DYNAMICS
Electric Boat
Groton, CT

Electric Boat Report No. PDE-301
27 July 2007

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **27 JUL 2007**	2. REPORT TYPE	3. DATES COVERED **00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE **Development of an Ultralight Pulse Gas Metal ARC Welding System for Shipyard Applications**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **General Dynamics,75 Eastern Point Rd,Groton,CT,06340**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**39**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

ABSTRACT

A significant cost in shipbuilding is setup during unit erection and outfitting to support welding operations. For small welding jobs such as hanger and tack welding, the labor associated with equipment relocation and setup can be a large part of the total cost of welding. This is primarily due to the need to move large and cumbersome welding equipment and cables through confined structures. As a result, many hangers and other light-duty welding tasks are carried out aboard ship using the shielded metal arc welding (SMAW) process (“stick” welding). This manual process is relatively slow, discharges considerable fume, requires removal of welding slag and electrode stubs, and may have lower welder appeal compared to the semi-automatic pulse gas metal arc welding (PGMAW) process. During certain phases of construction, it has not been economical to weld all hangers with PGMAW because of the high amount of labor required to move the cumbersome welding equipment around the boat. Additionally, shipboard space restrictions frequently interfere with power supply placement and accessibility for the PGMAW wire feeder, wire conduit, and welding torch.

As a result, a need was identified for a light-weight, man-portable PGMAW power supply with integral wire feeder for welding attachments and other light-duty welding tasks. Ideally, such a machine would be hand-portable by a single man, and by virtue of its size and space envelope, would allow welding of most hangers using the highly efficient PGMAW process. The need was also identified to provide or develop a compact, light-weight GMAW torch to maximize the number of welds that could take advantage of the new welding system. As a safety enhancement, a light-weight machine should require only single-phase 220V power compared to 3-phase 460V power. The light-weight machine would also need to be capable of welding with the shielded metal arc process since, because of space restrictions, not every hanger, or not the entire weld on every hanger, can be successfully welded using PGMAW.

Under a joint General Dynamics Electric Boat / Lincoln Electric program administered and managed by Advanced Technology Institute (ATI) for the Center for Naval Shipbuilding Technology (CNST), work was conducted to specify, build, test, and production prove a light-weight, man-portable welding system as described above. The welding system was designed and developed by Lincoln Electric around the needs identified by the Electric Boat shipyard. Extensive testing of prototype and Alpha manufacturing machines performed by both Lincoln Electric and Electric Boat refined the original design and validated the performance, usability, and welder appeal for use in the demanding shipyard fabrication environment.

Based on production trials and consideration of projected workloads, a projected first year after implementation savings of $312,000 was estimated. Second year savings were estimated to be $358,000, with $398,000 savings per year anticipated thereafter.

ACKNOWLEDGMENTS

This work was conducted by General Dynamics Electric Boat and the Lincoln Electric Company under contract to the Center for Naval Shipbuilding Technology (CNST), managed and operated by Advanced Technology Institute (ATI), Charleston, SC.

The author wishes to acknowledge the following individuals and companies for their contributions to this project: Kevin Carpentier and staff – ATI; Todd Kooken, Tom Matthews, and staff - Lincoln Electric; Frank Hanney – ABCO Welding and Industrial Supply, Waterford, CT; Andrew Stockton, Doc Holliday, Scott Wardwell, Alan Beaumier, Erin Foster, Mark Lafleur, Gregory Slaugenhaupt, and all the Electric Boat welders and foreman who participated in production trials and provided input into the equipment specification and evaluation – Electric Boat.

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BACKGROUND

A significant cost in shipbuilding is setup during unit erection and outfitting to support welding operations. For small welding jobs such as hanger and tack welding, the labor associated with equipment relocation and setup can be a large part of the total cost of welding. In ship construction, simple welds that take minutes to perform may take many hours or even several days to setup. This is primarily due to the need to move large and cumbersome welding equipment and cables through confined structures. As a result, many hangers and other light-duty welding tasks are carried out aboard ship using the shielded metal arc welding (SMAW) process ("stick" welding). This manual process is relatively slow, discharges considerable fume, requires removal of welding slag and electrode stubs, and may have lower welder appeal compared to the semi-automatic pulse gas metal arc welding (PGMAW) process. However, in most cases it is only necessary to bring a single cable lead with no power supply to the job area, which makes the SMAW process much quicker to setup. During certain phases of construction, it has not been economical to weld most hangers with PGMAW because of the high amount of labor required to move the cumbersome welding equipment around the boat. Additionally, shipboard space restrictions frequently interfere with power supply placement and accessibility for the PGMAW wire feeder, wire conduit, and welding torch. Figure 1 illustrates typical PGMAW welding equipment that was state-of the art 5 and 25 years ago. Although the newer equipment is considerably smaller and lighter, it is still not man-portable by a single man.

Lincoln V350 PRO   Gilliland CV600-FI

Figure 1: Illustration of GMAW-P Equipment, State-of-the Art 5 Years Ago (Left) and 25 Years Ago (Right)

The present manufacturing process involves the scheduling of the trades necessary to perform a specific welding activity. Activities to be performed by welders and supporting electrical technicians are scheduled with the aim of minimizing lost time while meeting shipyard schedules. Line foreman select the welding process to be used for a given job based on the size of the job and the confines of the space in which the work is to be performed. For small jobs, such as hanger and tack welding, where the labor associated with equipment relocation and setup can be a large part of the total cost of welding, the line foreman may choose to use SMAW in lieu of PGMAW. SMAW may also be selected when confines are such that the conduit between the wire feeder and PGMAW torch exceeds ten feet, or space restrictions exist making use of a conventional PGMAW difficult. Due to these restrictions and the cost disadvantages of setting up PGMAW for small jobs, a high percentage of small jobs in the Electric Boat Groton shipyard are currently welded using SMAW.

Once the welding process is selected, various trades execute the specific activities to accomplish the scheduled welding task. Workers relocate and setup welding equipment. More than one worker is required to relocate and setup PGMAW equipment because the equipment is relatively large and cumbersome. Electrical technicians connect welding power supplies to the 460 volt power system. Welding operations are performed. Upon completion, electrical technicians disconnect the power supplies from the 460 volt power system, and workers relocate equipment to support future welding activities. Cleanup tasks are performed as required. If SMAW was used, much more debris is present because of the slag and electrode stubs associated with this process.

As a result, a need was identified for a light-weight, man-portable PGMAW power supply with integral wire feeder for welding attachments and other light-duty welding tasks. Ideally, such a machine would be hand-portable by a single man, and by virtue of its size and space envelope, would allow welding of most hangers using the highly efficient PGMAW process. The need was also identified to provide or develop a compact, light-weight GMAW torch to maximize the number of welds that could take advantage of the new welding system. As a safety enhancement, a light-weight machine should require only single-phase 220V power compared to 3-phase 460V power. The light-weight machine would also need to be capable of welding with the shielded metal arc process since, because of space restrictions, not every hanger, or not the entire weld on every hanger, can be successfully welded using PGMAW.

PROJECT OBJECTIVE

The objective of this program was to develop a man-portable welding system that supports PGMAW shipyard welding operations. The specific initial minimum targets were as follows.

1. The welding system shall consist of a portable inverter PGMAW power supply and integral wire feeder with a maximum weight of 40 pounds.
2. The system shall also be SMAW capable to support welding where PGMAW is not possible or recommended.

3. The wire feeder shall accept two pound spools for PGMAW and be capable of feeding 0.035 inch diameter electrode.
4. The system shall operate on 220-volt single phase power.
5. Pulse welding current waveforms suitable for 0.035-inch diameter MIL-100S-1 electrode, and providing legacy calculated cooling rate versus weld metal yield strength performance are required.
6. The arc and puddle characteristics shall be comparable to those obtained using PGMAW equipment currently in use at Electric Boat.
7. The welding system shall be programmable and able to meet the requirements of various shipyards.
8. A compact, light-weight GMAW torch needs to be provided or developed to maximize the number of welds that can take advantage of the new welding system.

TECHNICAL APPROACH

The PGMAW process has been available since the mid-1960's. Since that time, Electric Boat has been the industry leader in the use and application of PGMAW, which is the primary welding process used at Electric Boat for ship construction. Development of improved PGMAW power sources and pulse waveforms over the years has resulted in much enhanced arc characteristics, puddle control, and weld penetration. As a result of this and the extensive Electric Boat experience, a PGMAW arc with certain characteristics is required for use in the Electric Boat shipyard. This arc must be constricted but not harsh, with a narrow plasma cone, must be penetrating, and must produce a weld puddle that is not overly fluid so high productivity welding can be successfully carried out in all positions. Additionally, the arc length must remain constant as the contact tip-to-work distance varies as the welder moves the welding torch along the weld and changes position (such as from vertical to horizontal around a corner). These are characteristics of value to all shipyards and heavy fabricators, not just to Electric Boat.

Until relatively recently, PGMAW power supplies were based on transformer-rectifier technology. In this technology, the arc and puddle characteristics were largely a function of the design of the transformer and associated electrical components. Only limited changes to the welding waveform were possible once the electrical components were selected. However, the technology was mature and well understood, and excellent power supplies meeting Electric Boat requirements were produced by at least three of the major power supply manufacturers. The downside of this traditional equipment was the weight (300 to 600 lb.) and size, which made the equipment relatively stationary, thus requiring long leads between the power supply and wire feeder (up to 100 ft. of lead was normal). Additionally, the wire feeder itself was rather large and cumbersome to move through cramped shipboard areas.

In the 1980's, inverter based power supplies started to appear. The reduced weight compared to the older technology was a major selling point, but these power supplies and

their associated wire feeders were still relatively heavy, large, and cumbersome, and therefore did not lend themselves well to portability. Furthermore, with the inverter-based welding machines, control of the arc, including the waveform in PGMAW, is obtained through programming of a controller rather than by the design of the electrical components. This programming requirement became the major impediment that prevented the successful use of an inverted-based PGMAW power supply at Electric Boat for many years. It appeared that the understanding of how to program the controller to obtain a waveform fully suitable for Electric Boat use, and control of the arc length and level of fluidity of the puddle, was generally lacking. As a result, previous generations of inverter-based machines generally produced arcs that varied in length as the torch position changed, arcs that were not sufficiently constricted to allow welding in deep grooves, and weld puddles that were much too fluid and difficult to control at the wire feed speeds and welding heat inputs that were in common use.

Therefore, the two major technical challenges required to develop a man-portable PGMAW machine were to reduce the size and weight while maintaining a suitable duty cycle (number of minutes in a ten minute period that the machine could operate without overheating), and providing arc and puddle characteristics that would be suitable for ship construction.

The Lincoln Electric Company and Electric Boat Corporation teamed to accomplish this task. Electric Boat experience with several new Lincoln Electric PGMAW power supplies had demonstrated that Lincoln had the necessary knowledge about the PGMAW process and waveforms to successfully program an inverter-based machine to perform up to Electric Boat expectations. This had been previously demonstrated in two Lincoln PGMAW machines currently in use at Electric Boat. Furthermore, preliminary discussions with Lincoln were very positive concerning the possibilities of developing the hardware to support a light-weight (“Ultralight”) welding system.

The equipment and associated programming development, to be principally carried out by Lincoln, was based on Lincoln Electric’s ISO 9000 recognized Stage Gate development process. This process, detailed as Lincoln Electric Specification OP114, “New Product Development Process”, had been successfully executed numerous times to develop new products for industry. In summary, the process:

- Outlines the phases associated with the development and introduction of new products.
- Defines the intent of each phase.
- Identifies the activities associated with each phase.
- Lists the required deliverables associated with each phase.

Phase 1: Definition. The process began with the Definition Phase where the Lincoln / Electric Boat team cooperated on development of the detail product requirements, which included arc performance, environmental application requirements, size and weight limitations, and user interactions (interface). Discussions and written correspondence were exchanged between the team members. The end product of this phase was the product

specification document that summarized all requirements. At this point, a go / no-go decision for continuation of the project into the next phase was made. This decision was based on whether the team was convinced that a man-portable PGMAW system could be successfully developed at an acceptable level of risk and meet all requirements as stated in the product specification document.

Phase 2: Feasibility. The objective of this phase was to produce a prototype unit capable of performing the required welding operations. Alternate switch mode (inverter) power supply topologies were investigated, and the topology which best met the product criteria was determined. Operational “breadboard” prototypes that confirmed criteria were built and tested and operated in a laboratory environment. In addition to written and verbal communication between the team members, a major design review took place at Lincoln Electric. At the end of this phase, a go / no-go decision for continuation of the project into the next phase was made based on the observed performance of the feasibility units and the confidence of Lincoln Electric as to whether the feasibility unit could be successfully repackaged to meet the size and weight goals of the program.

During this phase, work was started to develop a program for the inverter to run 0.035 in. diameter electrode. To accomplish this, Electric Boat provided basic information to Lincoln concerning the expected wire feed speed range and other basic parametric information. Lincoln then wrote a prototype program for use on the Lincoln V-350 PRO power supply, a modern inverter PGMAW machine that is in current use at Electric Boat. This program could be ported over to the prototype “Ultralight” machine when necessary. Electric Boat did extensive testing with this program and provided data and comments to Lincoln. The type of testing conducted consisted of vertical position mechanized bead-on-plate welding over a wide range of wire feed speeds with various parametric settings. The operating points and current and voltage readings were recorded along with observations. Additional testing was also conducted on typical hanger configurations in all welding positions in the semi-automatic mode. Lincoln refined the original program and it was tested again in a similar manner by Electric Boat. This provided an initial program which, when ported over to the “Ultralight” equipment, should produce close to the optimum welding characteristics.

Phase 3: Prototype. In this phase, units developed during the Feasibility Phase were refined to meet the overall internal and external packaging requirements identified during the Definition Phase. The reliability and safety of the units were verified using existing Lincoln Electric engineering procedures. Lincoln ported the 0.035 in. diameter control program developed on the V-350 PRO equipment over to the “Ultralight” equipment and did further refinement and improvement. Electric Boat tested a prototype unit to provide feedback to Lincoln Electric regarding operability, arc characteristics, wire feeding, and welder appeal. Since this prototype unit also featured packaging and a user interface envisioned to be close to the final version, Electric Boat also evaluated the user interface and case layout and features. This testing, which was extensive, involved approximately 10 shipyard and lab welders. In addition to verifying weld metal quality through volumetric nondestructive testing, weld metal mechanical properties testing was also performed to verify that results were within the ranges expected compared to historical data and comparative data obtained with the existing Lincoln V350 PRO equipment. Towards the end of this phase, a design review was held at Electric Boat. The tests and evaluations

performed during this phase were used to influence the manufacturing of the following Alpha test units.

Work was also performed on developing a lightweight PGMAW torch and quick-change SMAW stinger for use with the “Ultralight”. Through discussions with welders, it was determined that the ideal PGMAW torch for use with the “Ultralight”, especially for use on hanger welds where there can be significant space and accessibility restrictions, would feature a flexible neck, would weigh less, including the conduit, than standard torches, and would have a straight or relatively straight handle with a simple contactor switch. The torch would allow reaching through small areas to weld attachments. For the SMAW electrode holder or “stinger”, it was desirable to be able to interchange the stinger with the PGMAW torch quickly to enable a rapid change in welding process. It was also desirable to have a contactor switch mounted on the stinger grip in order to avoid a live electrode at all times. This would help to prevent inadvertent arc strikes when maneuvering the electrode in tight quarters prior to striking the arc in the work area.

The go / no-go decision point at the end of this phase was whether testing of the prototype unit was satisfactory and warranted manufacturing of the follow-on Alpha units.

Phase 4: Alpha Manufacturing. In this phase, Lincoln Electric manufactured ten units. These units incorporated changes identified in the prototype phase and represented the (near) final unit configuration. Five units were supplied to Electric Boat for product validation testing to confirm the product met customer requirements. The remaining five units were used by Lincoln Electric to perform a third round of reliability and safety testing per Lincoln Electric engineering procedures.

Phase 5: Electric Boat Field and Final Validation Testing. In this phase, Electric Boat thoroughly tested the five Alpha Phase units. One unit was subjected to testing in the Electric Boat Welding Laboratory to verify arc characteristics, waveforms, operability, user interface, and case features and design. This unit and the other four units were then provided to production for use with typical hanger and light welding applications. Two units were provided to the Electric Boat Quonset Point Facility in North Kingstown, Rhode Island, and the other three units remained at the shipyard in Groton, Connecticut. Prototype Ultralight PGMAW welding torches and SMA stingers were also concurrently provided for evaluation. Welding supervisors and welders were given a short training class to familiarize them with the equipment, the intended application of the equipment, and the general requirements for providing feedback on comments and suggestions from production personnel. Ease of use, portability, operability, welder appeal, and any operating problems (including downtime due to equipment failure or needed maintenance) were tracked. Periodic discussions were held regarding the evaluations and, as appropriate, the input was used to make modifications to the equipment.

During this phase, this final report was written, including an analysis of savings projected as a result of using the new equipment (based on data collected in the Field Trial Phase). Additionally, a PowerPoint presentation was prepared to aid in introducing the new system to other shipyards and other potential users.

This task was performed in accordance with References [1] and [2].

RESULTS AND DISCUSSION

Phase 1: Definition

The product specification document, Reference [3], was developed through numerous communications between Lincoln Electric and Electric Boat. Some of the most important product specification goals specified in Reference [3] are summarized below. Note that the product definition document did not cover the light-weight PGMAW torch or the quick change SMAW stinger.

- The unit will be designed as an ultra-light combination wire feeder / welder rated as follows (for PGMAW):

Duty Cycle	Volts	Amps (RMS)
100%	24	100
60%	25	125
30%	27	175
20%	28	200

- The unit will deliver enough power to weld using 0.035 in. diameter solid wire.
- The unit is a multi-process CV/CC machine capable of running the spray GMA, pulse GMA, FCA, SMA, and GTA processes.
- To minimize the input current, the unit is designed to operate with a high power factor on single-phase inputs. The peak current rating will be less than 30 amps for 230 volt input.
- The unit will be hand portable by one man using a handle or shoulder strap. The target total package weight is 40 pounds with a maximum acceptable weight of 45 pounds.
- Physical dimensions will be approximately 15 X 8.5 X 21 in. (Height X Width X Depth).
- The unit will support both 2 and 10 to 12 pound wire spools.
- The GMA process is limited to 0.025 to 0.035 in. diameter solid steel wire, and 0.030 to 0.035 in. diameter aluminum wire.
- The SMA process is limited to 5/32 in. diameter electrode or less.
- Output: Welding current range (continuous) = 5 to 200 amps. Maximum open circuit voltage = 76 volts. Welding voltage range = 10 to 28 volts.
- Pulse GMA wire feed speed range = 150 to 350 ipm.
- The unit will have built-in line voltage compensation and input current conditioning.

- The unit will have a cooling fan that runs when the output is energized and for 5 minutes after the output has been turned off.
- The unit will be thermostatically protected.
- The unit will have a door on the case for access to the spool and spool spindle.
- The unit will have a shielding gas solenoid.
- Shield gas preflow time will be adjustable in one second increments with a maximum value greater than 15 seconds.
- There will be a combination cold wire inch and gas purge switch.

Phases 2 and 3: Feasibility and Prototype

During these phases, numerous telephone conversations and email communications between Lincoln Electric and Electric Boat were conducted to refine the unit details. Items such as the output stud connection details, welding torch adaptor, input power connector, and user interface were discussed. At the same time, Lincoln Electric performed the work necessary to determine that a power supply and wire feeder could be successfully designed that would produce the desired output and duty cycle with the necessary constraints on physical size and weight. This included an investigation of alternate switch mode power supply topologies.

During the feasibility phase, work was conducted to develop a program for the inverter to run 0.035 in. diameter electrode. After Electric Boat provided basic information to Lincoln concerning the expected wire feed speed range and other parametric information, Lincoln wrote a prototype program for use on the Lincoln V-350 PRO power supply. Electric Boat conducted several rounds of testing with this program and modified versions of this program. Testing consisted of vertical position mechanized bead-on-plate welding over a wide range of wire feed speeds with various parametric settings, and all-position semi-automatic welds of shapes to plate (to simulate hanger welding). All work utilized a 3 foot length of 2/0 cable between the power supply and the wire feeder and 15 feet of #2 ground cable. These lead lengths and sizes approximate those to be used for the Ultralight welder. Tables I and II show the test results for the vertical position bead-on-plate welds and welds between the shapes and plates, respectively. Table III summarizes the evaluation of the 0.035 in. diameter program by several production welders. In this work, the production welders were instructed to identify the limits of the wire feed speed “sweet spot” where arc and puddle characteristics were optimized. They were also instructed to identity the highest wire feed speed where the arc was still controllable. The work shown in Tables I to III was all conducted using the last revision of the program developed for the V350, Rev. 0.2.

The overall results of this work indicated that the Rev. 0.2 program was acceptable for production welding, and this revision was an improvement over the other software revisions tested. However, specific issues or concerns, none of which were serious, were noted as follows:

1. The bead-on-plate welding indicated a general problem with spatter over a fairly wide range of wire feed speeds, although no spatter problems were noted by the production welders while welding on shapes. Spatter seemed to be largely limited to the bead-on-plate welds made in the vertical position.

2. The parameters used for the all position welds on attachments were found to be satisfactory, and were an improvement over those used with previously tested revisions of the program.

3. Overall, the shipyard welders were pleased with the 0.035” diameter program.

4. The observation was made that there was enough adjustment available in the arc control setting to allow proper “tuning” of the arc characteristics to accommodate the welding situation and personal welder preference.

5. The optimum wire feed speed range appeared to be 211 to 221 ipm. The maximum wire feed speed where there was a controllable arc in all positions was 271 ipm. See Table III.

6. The wire feed speed needs to be at or below 250 ipm to avoid excessive puddle heat and fluidity.

7. Varying the Vset (voltage control that is pre-set by the user at the wire feeder) value has little effect on the arc appearance. Varying the arc control has a much larger effect, with small changes in arc control (for example, a change of 5) having a relatively large effect.

The Rev 0.2 program that was developed on the V-350 PRO power supply would serve as the starting point for developing a program for the Ultralight.

Table I – Vertical Position Bead on Plate Welds – V-350 PRO With Rev 0.2 Software

Wire Feed Speed (ipm)	Current (A)	Voltage (V)	Vset	Arc Control	Comments
352	120–125	~22.5	22.5	120	Hot puddle. Some spatter.
324	110-115	~21.5	20.9	125	Hot puddle, spatter.
298	110-115	~21.5	21.3	125	Hot puddle, spatter.
274	105-110	~21	20.7	125	Hot puddle, possibly a little less spatter.
250	100-105	~21	20.7	120	Still too hot, some spatter.
224	95-100	~21	20.7	120	Acceptable characteristics, but still too hot with some spatter.
202	85-90	~21	20.7	115	Acceptable characteristics. Sable.
182	~75	~19	19.1	105	Acceptable characteristics, but a little cold.

Table II – All Position Welds – Shapes to P late – V-350 PRO With Rev 0.2 Software

Wire Feed Speed (ipm)	Position	Current (A)	Voltage (V)	Vset	Arc Control	Comments
202	OH	100-105	~20.5	19.9	115	Acceptable characteristics.
202	V	95-100	20-20.5	19.9	115	Acceptable characteristics.
202	F	90-95	20-20.5	19.9	115	Acceptable characteristics, slight spatter.
202	H	95-100	20-20.5	20.2	115	Acceptable characteristics.
202	F	95-100	20-20.5	20.2	115	Acceptable characteristics, less spatter than above.

Table III – Production Welders, All Position Shapes to Plate Welds, V-350 PRO With Rev 0.2 Software

Wire Feed Speed (ipm)	Position	Current (A)	Voltage (V)	Vset	Arc Control	Comments
221	All	90	18.8	18.9	120	High end of “sweet spot”. Arc Control range in “sweet spot” is 110 to 130. This adjustment of the arc control results in a ± 0.5 volt variation.
211	All	80	17.9	18.0	120	Low end of “sweet spot”. Arc Control range in “sweet spot” is 110 to 130. This adjustment of the arc control results in a ± 0.5 volt variation.
271	All	105	20.8	21.0	120	This is the upper end of the range where there is a controllable arc.

Notes to Tables I, II, and III

1. V = vertical position; H = horizontal position; F = flat position; OH = overhead position, All = all position.
2. Current measured using calibrated analog millivoltmeter / shunt.
3. Voltage measured between wire feeder drive rolls and work using calibrated VOM.
4. Vset is the voltage preset on the wire feeder and displayed in the digital voltage meter on the power supply front panel.
5. The Arc Control provides for some adjustment of the arc length and arc characteristics around a given wire feed speed.
6. (Tables I and II only). The data presented in these tables represents the best operating conditions arrived at by varying the Vset and arc control settings at each constant wire feed speed.

Prototype Unit

Electric Boat received the prototype Ultralight system for testing on March 23, 2006. This unit, with the tentative name of EB-200 MP, weighed in at 40 pounds, well within the goals of the program. One significant item that was included on the prototype unit was the single attachment point where the GMA torch or SMA electrode holder is connected. The GMA gun conduit plugs directly into this attachment point. The SMA stinger lead also attaches

directly using the same fitting as the GMA torch, but without the provision for the shielding gas. This is a significant improvement over other existing systems as it takes just a minute or two to make the change from GMA to SMA or visa versa. The advantage of this arrangement is that it allows a welder to rapidly change over from one process to the other, increasing the chances that the more efficient GMA process may be used, where possible, on a hanger that requires some SMA welding because of an accessibility restriction. Figure 2 shows the prototype unit with a GMA torch and ground lead attached.

The system was evaluated by weld testing, and operational and user interface issues were noted. The case and packaging were also evaluated. The more significant items are listed below along with the Lincoln Electric *comment or resolution*.

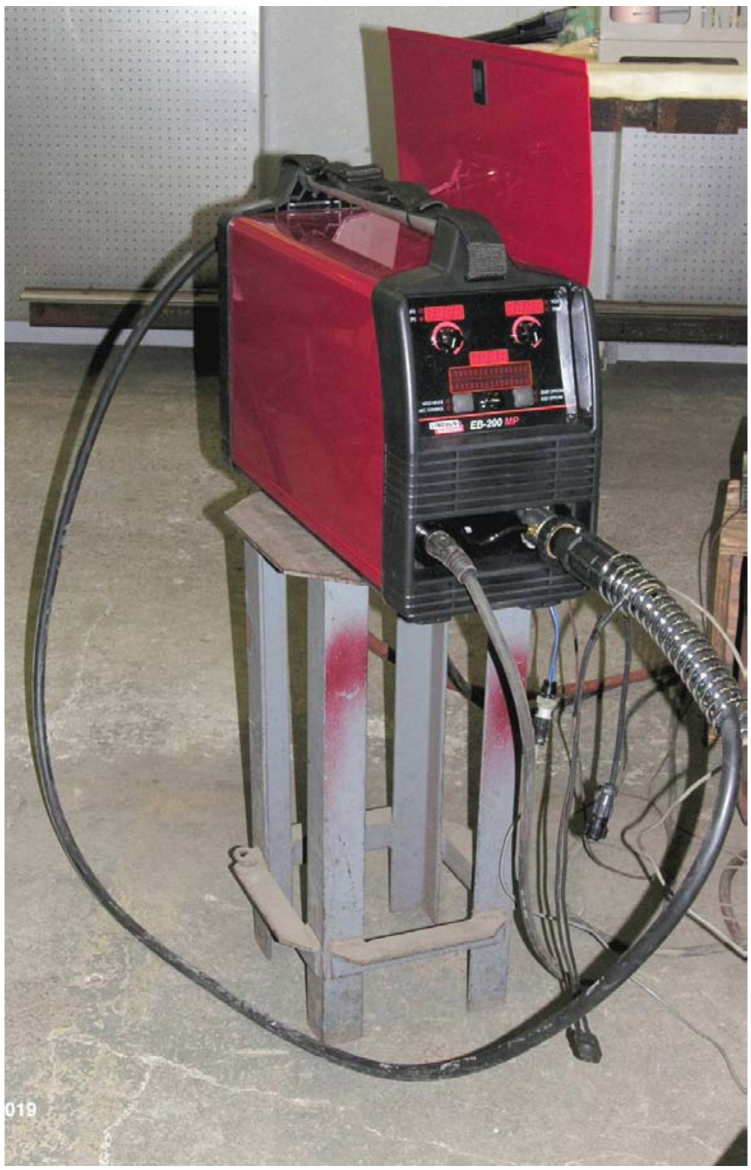

Figure 2: Prototype EB-200 MP “Ultralight” System With GMA Torch and Ground Lead Attached. Side Panel Door Open for Access to Wire Feed Motor and Wire Spool.

Case and Packaging

- The hinges on the door over the wire spool and wire feed motor appeared to be somewhat insubstantial. *Lincoln would look into improving the hinge*.
- It was not clear if the machine could be used lying in its side. *Lincoln would determine if this was possible.*
- The front panel knobs were exposed and could be damaged while the machine was being moved or inadvertently changed under normal use. *Lincoln would investigate inclusion of some type of cover.*
- A preference was expressed by Electric Boat for a rocker style on-off power switch in place of the rotary switch supplied. *Lincoln was already looking into this to save interior space in the case.*

Operational / User Interface

- The front panel controls were found to be well thought out and easy to operate. The display brightness is good for the shipyard environment. Figure 3 illustrates the front panel controls and typical settings for PGMAW and SMAW.
- The pre-purge time needs to be adjustable with a maximum closer to 20 seconds than the 3 or 4 seconds on the machine. *The prototype machine was updated by Lincoln to allow 19.9 seconds of pre-purge time. This will be incorporated into the Alpha machines*
- The prototype machine featured a single power supply receptacle for the positive cable (welding torch or SMA electrode holder). With the GMA torch installed in the power supply receptacle and the mode set to #1 (SMA mode), and the contactor is set to "on", the torch contact tip and electrode are "hot". This can result in an inadvertent arc strike and poses a potential safety hazard. *It was decided to configure the machine to always have the contactor "off" until the contactor is engaged manually with the switch on the GMA gun or a contactor on/off switch on the SMA electrode holder. The addition of a contactor switch to the SMA electrode holder will also help welders avoid inadvertent arc strikes as the welder positions the electrode in tight quarters prior to welding.*
- Lincoln was asked to determine the machine duty cycle for SMA welding with 1/8 in. diameter electrode at 130 A. *Lincoln would develop this number.*

Weld Testing

All testing was conducted using a ground cable made up of 15 ft. of #2 wire, a 1 ft. 1/0 pigtail with a twist-lock connector on one end (attached to an in-line ammeter) and an eyelet on the other end, which was attached with a bolt and nut to an eyelet on the #2 cable, and 12 ft. of 1/0 cable attached to a ground clamp with an eyelet and the other end attached to the ammeter via a twist-lock connector.

Figure 3: Front Panel Controls and Display on Prototype EB-200 MP “Ultralight” System With Typical Setting Displayed for PGMAW (Left) and Shielded Metal Arc (Right)

All electrode was ESAB 0.035 in. diameter, on 8 in. spools, either MIL-70S-3 or MIL-100S-1, as noted. Shielding gas was 5% CO_2 - 95% Ar. A 35 cfh flow rate into a #8 nozzle was used for mechanized bead on plate testing. Semi-automatic welding used a 30 cfh flow rate into a #6 nozzle. In both cases, the torch was a standard 200A OXO, Model AP20.

Instrumentation included a calibrated analog ammeter (shunt, mV meter) and VOM (Simpson 260).

Initial testing used mechanized vertical position bead on plate welding over a range of wire feed speeds to determine optimum settings (arc control, trim/voltage). Both MIL-70S-3 and MIL-100S-1 wires were used. As shown in Tables IV and V, there appeared to be a sufficiently wide range of operating conditions. The optimum settings were different for each wire tested, probably due to slight differences in wire processing. There was sufficient range in both the arc control and trim/voltage settings to accommodate these differences. In nearly all cases, low or spatter free welds were obtained at the settings indicated. The arc lengths were consistently short and very stable.

The bulk of the testing was conducted using Mode 2 (non-synergic). The small amount of Mode 3 welding (synergic) conducted indicated that the starting parameters pre-programmed in the software were not appropriate for the MIL-70S-3 electrode used. In all cases, adjustments (higher arc control and trim/voltage settings) were necessary to eliminate spatter. In the one test run in Mode 3 with MIL-100S-1 electrode, the starting parameters also needed to be adjusted to eliminate spatter, but they were closer to those that were ultimately used. It is observed that due to variations in lot-to-lot wire processing, changes in processing between vendors, and the need to accommodate changes in welding torches and variations in arc preferences among welders, that Mode 2 would appear to be the only mode required for pulse welding.

One test was run on the V350 PRO with the 0.035 in. diameter program, Rev 0.2 that was used to help develop Mode 2 in the EB-200 MP. In direct comparison testing, the welding parameters used with the V350 PRO and the EB-200 MP were nearly identical at the same wire feed speeds. Follow-on testing involved welding angle iron, pipe, flat bar, and square tube to a vertically mounted steel plate. Six welders used the equipment and provided comments. Welding was conducted in all welding positions, with transitions made from the vertical welding position to the overhead welding position to the horizontal fillet position, and from the vertical welding position to the horizontal fillet position, among others. Specific attention was paid to any variation in the arc length as the torch position was changed and as the weld went around corners.

Table IV – EB-200 MP Prototype, Vertical Position Bead on Plate Welds, 0.035" dia. MIL-70S-3 Electrode

Wire Feed Speed (ipm)	Current (A)	Voltage (V)	Vset	Arc Control	Comments
Program Mode 2 (Non-Synergic)					
140	67	18.2	18.6	100	Appears to be the bottom end for a reasonable arc.
160	73	18.8	19.1	105	
180	77	19.2	19.7	108	
200	85	19.6	20.3	110	
220	90	20.0	21.0	121	
240	95	20.2	21.3	130	
260	99	20.8	21.7	140	
280	110	21.0	22.0	149	
300	115	21.3	22.6	150	Arc Control could not be advanced above 150.
320	123	21.9	23.1	150	
340	127	22.1	23.5	150	
360	129	22.8	24.1	150	
380	135	23.2	24.6	150	
400	145	23.8	25.2	150	Ran hot. Appears to be the top end.
Program Mode 3 (Synergic)					
220	84	19.8	19.5	117	Starting Vset and AC *All of these welds had more spatter than the comparable*
			20.9	122	Final Vset and AC *welds with mode 2.*
240	94	19.8	19.9	127	Starting Vset and AC
			20.7	135	Final Vset and AC
260	105	20.0	20.3	134	Starting Vset and AC
			21.4	144	Final Vset and AC

Table V – EB-200 MP Prototype, Vertical Position Bead on Plate Welds, 0.035" dia. MIL-100S-1 Electrode

Wire Feed Speed (ipm)	Current (A)	Voltage (V)	Vset	Arc Control	Comments
Program Mode 2 (Non-Synergic)					
140	63	18.2	18.5	98	Appears to be the bottom end for a reasonable arc.
160	67	18.5	18.8	102	
180	77	18.9	19.2	108	
200	80	19.2	19.6	117	
220	86	19.3	20.0	121	
240	89	19.5	20.1	129	
260	93	19.8	20.4	136	
280	100	19.9	20.5	141	
300	101	20.2	21.0	145	
320	112	20.3	21.3	149	
340	115	20.6	21.6	150	Arc Control could not be advanced above 150.
360	119	21.1	22.1	150	Some spatter.
380	122	21.5	22.5	150	Some spatter.
400	128	22.0	23.0	150	Some spatter. Ran hot. Appears to be the top end.
Program Mode 3 (Synergic)					
220	77	19.1	19.5	105	Starting Vset and AC *Needed to adjust settings to*
			19.8	107	Final Vset and AC *reduce spatter.*

Overall, Mode 2 welding was excellent. The arc length did not vary as the tip-to-work distance changed while transitioning positions. The arc length was consistently short and steady, and there was enough latitude in control adjustments to accommodate variations in electrode operability and individual welder preferences. The puddle was always controllable. SMA welding conducted with 3/32 and 1/8 in. diameter electrodes was excellent, particularly with 3/32. It was noted that the arc was very smooth and consistent.

Based on the EB weld test results, it was recommended that Mode 3 not be included on the Alpha machines.

Overall, testing was judged to be very successful. The arc and puddle quality, ease of use, machine packaging, and user interface met all expectations. The 40 pound system weight was well within program goals.

Prototype Light- Weight Welding Torches

A light weight GMA welding torch was recognized as an important item to be used with the Ultralight welding system. Ideally, the torch would be compact, allowing accessibility in the tight quarters where the advantages of the Ultralight system would be maximized. The

torch would have to be lighter in weight than currently available torches, comfortable in the welder's hand, and easily manipulated. None of the commercial torches examined had all of the desired attributes. Therefore, a prototype torch was developed by Electric Boat, ABCO, and Lenco. The prototype torch had an 8 in. long flex-neck head and was lighter in weight and more compact than the standard 200A OXO torch. Weld testing of this torch verified that its performance (arc and puddle characteristics, welding current and arc voltage for a given wire feed speed) was comparable to the OXO model. Figure 4 shows the prototype Ultralight GMA torch. Note that the contactor switch (on - off rocker) is mounted in a box attached to the torch handle. The switch itself and the mounting are non-typical. The most common switch is a momentary on - off lever switch mounted directly on the torch body.

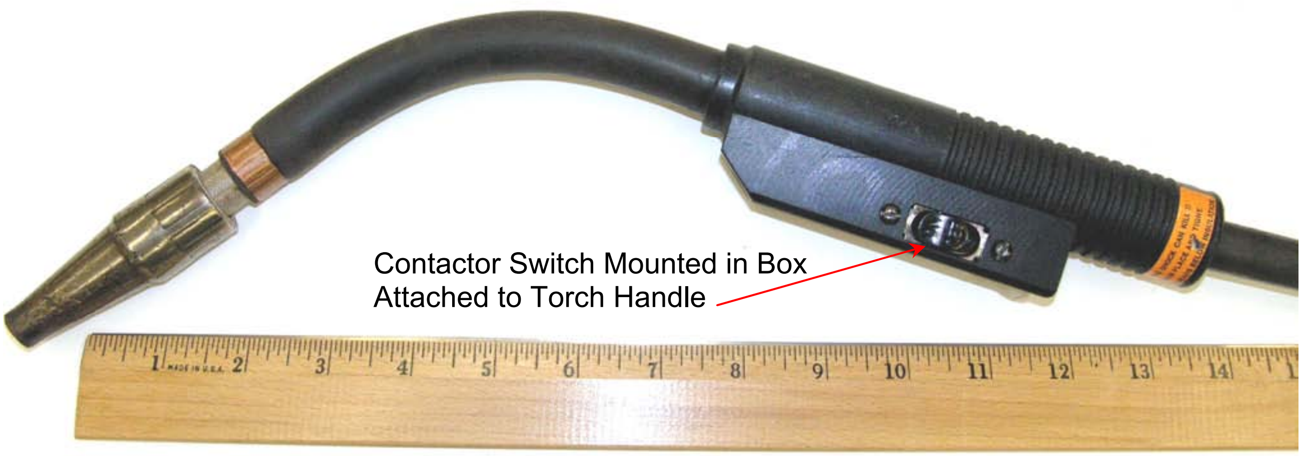

Figure 4: Original Prototype Ultralight GMAW Torch With 8 Inch Flex Neck

Although the main purpose of the Ultralight system was to allow PGMAW to be used in place of SMA, the reality of shipboard welding is that not every weld or all parts of every weld can be successfully made using PGMAW. No matter how light and compact a GMA torch might be, some SMA welding may still be necessary as accessibility considerations dictate. If the Ultralight welding system had been designed with only PGMAW in mind, then it would be necessary to have SMA leads hooked up to conventional power sources in addition to the Ultralight in the fabrication area. This would discourage use of the Ultralight since once the SMA leads are in place, there would be less driving force to bring Ultralights into the area. With the Ultralight system capable at both PGMAW and SMA welding, the separate SMA leads are no longer necessary, but it is still necessary to be able to switch back and forth between the two processes on the Ultralight quickly. This led to the development of the Ultralight SMA stinger shown in Figure 5. The stinger is made from a standard, commercially available unit with the addition of the same contactor switch and housing box used for the GMAW torch attached to the torch handle. This stinger was designed to connect to the Ultralight using the same connector as on the Ultralight GMA torch. The changeover from GMA to SMA involves simply removing the GMA connector from the receptacle mounted on the front of the Ultralight power supply, cutting the wire electrode at the base of the receptacle, disconnecting the contactor switch connector, and then attaching the Ultralight stinger connector and contactor switch. Once the program

mode is switched from PGMAW to SMA on the front panel, the welder is ready for SMA welding. The entire process takes under a minute.

Figure 5: Prototype SMA Stinger

Phase 4: Alpha Manufacturing

In this phase, Lincoln Electric manufactured ten units. These units incorporated changes identified in the prototype phase and represented the (near) final unit configuration. Figure 6 shows the Alpha Ultralight system.

- The hinges on the door over the wire spool and wire feed motor were improved by switching to a stronger style hinge.
- Lincoln determined that the unit should not be used lying on its side.
- A clear plastic flip down cover was installed over the front panel knobs to prevent damage while the machine is being moved or inadvertent knob movement under normal use. (Visible in Figure 6).
- A rocker style on-off power switch was used on the back panel in place of the rotary switch in the prototype unit.
- The shielding gas pre-purge time was made adjustable up to 19.9 seconds.
- The unit was configured such that the contactor is “off” until the contactor is engaged manually with the switch on the GMA gun or a contactor on/off switch on the SMA electrode holder.
- The duty cycle tables provided with the Alpha machines are shown in Tables VI and VII. The duty cycles shown in Table VII for PGMAW exceed program goals.

Figure 6: Alpha Ultralight Unit. Note fold down protective cover over controls and access to wire feeder under right side flip-up panel.

Table VI – EB-200 MP Prototype Duty Cycle for Shielded Metal Arc, Mode 1

Current, Average (Amps)	Voltage, Average (Volts)	Duty Cycle (%)
70	22.8	100
80	23.2	100
90	23.6	100
100	24.0	100
110	24.4	75
120	24.8	65
130	25.2	55
140	25.6	45
150	26.0	35
160	26.4	30

Table VII – EB-200 MP Prototype Duty Cycle for Pulse GMA, Mode 2

Wire Feed Speed (ipm)	Current, Average (Amps)	Current, RMS (Amps)	Duty Cycle (%)
150	70	121	100
200	90	145	70
250	100	165	50
300	110	180	40
350	120	190	30

Phase 5: Electric Boat Field and Final Verification Testing

Pre-Production Testing

One Alpha unit was subjected to testing in the Electric Boat Welding Laboratory to verify arc characteristics, waveforms, operability, user interface, and case features and design. The prototype and the Alpha machines were set up side-by-side and alternately run using the same spool of MIL-100S-1 electrode, the same standard OXO and prototype Ultralight (see Figure 4) welding torches, and the same machine settings (wire feed speed, arc control, and Vset). All welds were vertical position bead-on-plate welds. The wire feed speeds used, 180, 220, and 260 ipm, bracketed the range most likely to be used in production welds. SMA welding was also conducted using 3/32 in. diameter MIL-7018-M electrode and the prototype SMA electrode holder (see Figure 5) with the same contactor switch arrangement as was on the prototype GMA torch. The results of these comparisons are shown below.

- Pulse GMA
  - The Alpha machine welded satisfactorily when tested with the OXO 200A gun and the prototype Ultralight gun. The only exception was at the lower (180

  ipm) wire feed speed where there was some “ball transfer” with the Alpha machine.

  - The arc characteristics were judged to be excellent overall and fully suitable for the intended applications.

- SMA
  - SMA welding was excellent. Many welders commented that the Ultralight was one of the best SMA machines they had ever used. The following items are noted for information.
    - When the contactor button is turned off as the arc is extinguished, the power supply meters will display the amps and volts for several seconds thereafter.
    - If the arc is extinguished and the contactor is not turned off, the meters will not display the amps and volts actually used, and another rod may be inserted into the holder and welding can continue as with a standard stick power supply.
    - This behavior is as intended, but needs to be explained to the welders being trained with the equipment.

Prior to putting the five Alpha units into production, it was necessary to write welding procedures specifically for the units (PGMAW only). This required one Level II procedure qualification in accordance with NAVSEA Technical Publication S9074-AQ-GIB-010/248 to extend the welding current range previously qualified for PGMAW to a lower minimum level. This vertical position test assembly was successfully inspected by magnetic particle testing and radiography, demonstrating the ability of the Ultralight to produce high quality welds. Additionally, two test assemblies were welded at two different calculated cooling rates using MIL-100S-1 electrode and tested for weld metal mechanical properties (tensile and impact properties). The 29 kJ/in heat input vertical position test assembly had 100 ksi weld metal yield strength, compared to 101 ksi yield strength predicted based on the Electric Boat calculated cooling rate versus weld metal yield strength correlation for pulse GMA with MIL-100S-1 electrode. Similarly, the 45 kJ/in heat input vertical position test assembly had 92 ksi weld metal yield strength, compared to an 89 ksi yield strength predicted based on the same correlation. In both cases, weld metal Charpy V-notch impact test results far exceeded minimum specification requirements. These results served as verification that the Ultralight waveform produced the predicted weld metal mechanical properties (and therefore, predicted calculated cooling rates) when the heat inputs are calculated using averaging meters, thereby ensuring that the required weld metal mechanical properties are produced using the existing welding procedure heat input controls.

Several welding procedures specific to the EB-200 MP were written. The procedures were structured to limit the maximum thickness of one of the two members being joined. This was done in order to prevent the Ultralight from being used to weld thick joints, which would be outside of the intended use for the equipment.

Welder and Welding Supervisor Training

Prior to starting production evaluations, a short training/familiarization class was held with several groups of welders and welding supervisors. The objective was to introduce the new equipment and emphasize the unique features and advantages of the Ultralight system. Other items reviewed included equipment setup, selection of the desired welding mode and welding parameters, switching processes and welding torches between GMA and SMA, and the machine duty cycle ratings.

Production Testing

Two Ultralight units were provided to the Electric Boat Quonset Point Facility in North Kingstown, Rhode Island, and the other three units remained at the shipyard in Groton, Connecticut. Prototype Ultralight PGMAW welding torches and SMA stingers were also concurrently provided for evaluation. As intended, the units were typically used for hanger and light welding applications.

Groton Usage and Experience

The standard shipyard power for welding equipment is 460V 3-phase 100A. The Ultralight uses 220V single-phase 30A power, which is not directly available in all locations within the Groton shipyard or aboard ship. As a temporary solution, Groton purchased several e-Cart™-Jr. temporary power distribution centers (Ericson Manufacturing Company, Willoughby, Ohio). The e-Cart™-Jr., built around a tubular steel handcart, contains the electrical circuitry (transformer, fused main disconnect, and distribution panel) to transform the 460V 3-phase current into 220V single-phase power. As configured, the carts purchased by Electric Boat each provided two outlets to attach the Ultralight equipment. In use, the cart would be wheeled or otherwise moved to the needed location and attached to the standard shipyard power.

Initial usage at Groton was on an application that was at the upper end of the thickness limit allowed by the Ultralight welding procedure, and consisted of longer weld segments than found in typical hangers. This application was not in-line with the intended use of the Ultralight equipment since it was non-typical of low duty cycle hanger welding jobs. The job was perfectly suited for a larger welding machine with a higher duty cycle running larger diameter electrode with higher welding currents. Although the welds deposited were fully satisfactory, the machine did shut off several times during welding, as it should have done, due to exceeding the duty cycle limitations of the equipment.

Subsequent usage at Groton was on typical hanger and light welding jobs.

One of the power supplies, unit #4, developed a fault where there was a constant 100VDC between the power supply output terminals with the contactor off. The unit was returned to Lincoln Electric for examination and repair. Lincoln found that the root cause was a bad solder joint on a control board. This solder joint was part of a rework that was done to the control board. The end result was a component failure that resulted in 100VDC always being across the output studs. The original rework was done to add environmental protection to the PC boards. Although a thorough inspection and check had been done on

this machine as manufactured, only an abbreviated test that did not include looking at the individual circuit that failed was conducted after the rework. Electric Boat had a concern on the failure mode which resulted in 100VDC being across the output studs. Lincoln reviewed some possible options to see if there was anything that could be done to protect against this type of failure mode. It is noted that the Ultralight is designed to IEC 60974-1 which is the American National Standard for Industrial Power Sources. This standard requires that a device failure cannot result in more than 113VDC across the machine's output studs. After repair by Lincoln, this machine was returned to production work at Groton. After a short period of time, this same machine developed a problem with the same symptoms as described above. Lincoln found that the root cause of this problem was an intermittent connection between two boards that developed as a result of the repair procedure used in the previous repair cycle. This was the first time that Lincoln had used this particular board arrangement and indicated that in the future, revised repair guidelines would be required to prevent such problems. Lincoln redesigned one of the control boards to prevent such a failure from putting open circuit voltage across the power supply studs, and was planning on implementing a supervisory circuit that, if recognizing a failure that could put open circuit voltage across the output studs, would shut down the power supply and indicate a fault message.

Quonset Point Usage and Experience

Initial usage was primarily in the pipe shop welding small pipe hangers, small foundations, structures, and temporary attachments. Welding was performed in the overhead, flat, and vertical positions, primarily on high strength steel. Over 150 welds were performed. An initial unscientific “estimate” of a 10% potential cost savings due to using the Ultralight for hanger welds in place of the conventional equipment was offered by the users. (See the section titled “Estimate of Production Cost Savings With the EB-200 MP Ultralight Welding System” for further discussion on this topic). Additional production work was accomplished on decks and construction modules.

One machine developed a fault where there was a constant 100VDC across the output terminals. This failure appeared to have the same symptoms and a similar cause as the Groton based machine previously discussed. In this case, the failure was due to a failed IGBT (insulated gate bipolar transistor) in the output circuit, versus an intermittent gate drive connection and a bad solder joint from a reworked circuit in the failed Groton machine previously discussed. For the production versions of the EB-200 MP, the following modifications will be made to correct the IGBT related problems and insure that if a failure of this nature exists, the machine will have the ability to shut itself down to prevent unexpected voltage across the output studs.

a. The gate drive circuitry was redesigned so that an intermittent gate drive will result in a safe “always off” mode for the device, preventing the constant open circuit voltage in case of a failure.

b. The communication link between the controls and the output board (where the failed IGBT is located) was redesigned for better noise immunity to prevent IGBT failures under extreme conditions.

c. Implement short term current limits to reduce stresses in the IGBT during high current transient conditions.

d. Redesign the output stage module to improve the symmetry and current balance on the six output IGBT's.

Additionally, it appeared that the 220V single-phase power currently available at the Quonset Point facility was not sufficient in some locations. The Ultralight is designed to use a 30A circuit, but in some areas, the yard only has approximately 20A available. This resulted in an "error code 31" indicating insufficient input power and the inability to run the equipment. Lincoln Electric tested one of the Quonset Point machines to verify that the machine was not at fault. Therefore, the Quonset Point machines had to be used in areas where sufficient power was available. When Ultralight machines are purchased for production use, the proper infrastructure will also have to be provided to power the machines.

Specific Comments Concerning the EB-200 MP Ultralight System (Groton and Quonset Point)

Comments from the Groton and Quonset Point welders were in two classes: comments directly about the equipment and the machine welding and usage characteristics, and comments about what they would prefer to weld with, which is not necessarily related to the equipment under evaluation. The welder comments are presented below, with analysis in *italics*.

- Comments directly about the equipment
    - All welders thought the operator controls and power supply connections were easy to operate and user friendly.
    - Positive comments were made about the light weight of the machine.
    - One welder made positive comments about the small size of the GMA torch and the light-weight conduit. Although the torch fits in tight spaces, that welder judged the trigger to be too sensitive, causing the arc to turn off at times from lack of pressure. *(It was not identified if this comment refers to the original Ultralight torch, or one of two "new" prototype torches, discussed later. Only one such comment was received.)*
    - One welder commented that the wire binds up easily, especially when welding around corners and moving the torch head while welding. *(This problem was not identified as a generic problem. Without further details and analysis, it is not possible to determine if this problem was caused by the Ultralight wire feeder, the torch, the conduit liner, a problem with the wire itself, or even the contact tip.)*
    - Most welders liked the arc characteristics for both pulse GMA and SMA. Positive comments were made about the deposited weld quality and bead appearance, and the reduction in welding time required to complete a joint (compared to standard SMA welding). Some thought that the PGMA arc characteristics were sensitive and

difficult to control, and the arc will sputter if the arc length is not held steady. *(Based on the overall experience, the PGMA arc length control and arc quality were judged to be excellent, and better than many of the full-size PGMA machines currently in use. The less than ideal arc characteristics mentioned above were most probably due to a problem with the physical setup or the choice of parameters. As identified in the applicable Electric Boat EB-200 MP welding technique sheets, there is an optimum range of wire feed speeds where the arc characteristics are optimized. It is not known if the less than ideal arc characteristics were caused by the welder using wire feed speeds outside of the optimum range.)*

- One Quonset Point welder had difficulty in producing good bead appearance. There was also a comment that in pulse mode, the EB-200 MP produces welds with more spatter than other PGMA machines. *(This comment is due to a lack of experience with the equipment and the smaller size electrode. It is not related in any way to the EB-200 MP system or the pulse waveform. In testing before shipyard trials, the EB-200 MP produced several X-ray quality welds. All observations of bead appearance and quality were excellent.)*

- The welders commented that housekeeping concerns were greatly reduced with the Ultralight (as opposed to welding using SMA) as less cover up of adjacent areas and clean up time are reduced.

- One welder thought that equipment setup was quick and easy, while another remarked that the set up time was longer than for a conventional pulse machine. *(This comment is based on a small amount of experience with the equipment and reflects a typical shipyard reaction to "something new", where time is required to get used to new equipment.)*

- All welders liked the ease with which the equipment could be switched from pulse GMA to SMA. Also, time was saved since it was no longer necessary to drag stick leads through an area to do incidental SMA welding either on the assigned job or just in the general work area. *(These observations highlight distinct advantages over the current equipment and illustrate that with the Ultralight system, it will be possible to eliminate stick electrode leads entirely from areas where light welding is being performed. The fact that it is easy to switch back and forth between the processes bodes well for pulse GMA as there is no a penalty for setting up with pulse GMA and then switching to SMA, as needed.)*

- There was near unanimous agreement that the contactor switch (style, location, and mounting of the switch) on the original prototype Ultralight torch body was not comfortable and was unsuitable. No one complained about a nearly identical switch and mounting on the body of the SMA stinger. *(The switch on both torches is an on–off rocker switch. It must be moved to "on" to begin the arc starting process with GMA, and then turned to the "off" position to extinguish the arc. For SMA, the switch is turned to the "on" position when the welder is ready to strike the arc, but it does not need to be turned "off" when the welder breaks the arc; the arc is broken in the normal way for the SMA process and the switch can be left "on" in preparation for welding the next rod, or turned "off" at any point. Since the*

mounting location of the switch on the GMA torch is not ideal, and the switch is rather small and difficult to locate, especially with the gloved hand, it is a cumbersome operation, especially since it is necessary to extinguish the arc by operating the switch – something that is not required for SMA.)

- There was unanimous agreement that the neck on the original prototype Ultralight gun was too large, and one welder suggested that the torch handle should have a better grip. It was suggested that the handle have molded-in finger grips to prevent slipping. *(These are all valid points concerning the original prototype Ultralight gun.)*

- All welders liked the remote contactor switch on the SMA stinger. *(The remote contactor switch allows the welder to snake the electrode through multiple obstructions without having to be concerned with a live electrode, and therefore an inadvertent arc strike. Inadvertent arc strikes generally require repair, and therefore are desirable to eliminate.)*

- One welder thought the plastic parts would be susceptible to damage. *(Most modern power supplies do contain some plastic parts. The plastics chosen for the Ultralight are particularly durable and resistant to the normal handling and treatment expected in a shipyard.)*

- Comments about preferences

  - Several welders would like to see the equipment capable of pulse GMA welding with 0.045 inch diameter wire. They were more comfortable (and more familiar) with the larger size wire. This was especially true for Quonset Point Facility welders. There was also a comment that a higher duty cycle would be beneficial. *(These comments reflect the welders' comfort level with 0.045 inch diameter electrode and larger, higher duty cycles machines. The maximum pulse GMA electrode size capable of being used in the Ultralight equipment is 0.035 inch diameter. This is based on the power output capability of the equipment for a machine of the size and weight targeted. For the thickness material allowed to be welded by the Ultralight, 0.035 inch diameter electrode is perfectly satisfactory. As the welders gain more experience with using 0.035 inch diameter electrode with the Ultralight system, their comfort level will increase. Although increasing the machine duty cycle would be beneficial, that would probably result in increased weight and size, which is contrary to the primary objectives for this equipment. The jobs intended to be used with this equipment do not require a high duty cycle. Keeping the duty cycle and the power output capability of the equipment on the low side makes practical the lightweight, portable equipment that has been developed, and also enables the use of small, lightweight welding torches and lighter gage welding cables. It is true that many of the hangers and other attachments are of sufficient thickness that they can be successfully welded using 0.045 inch diameter electrode. For the Quonset Point Facility, where nearly all hangers are currently welded using PGMA with 0.045 inch diameter electrode, switching to 0.035 inch diameter electrode is not beneficial, unless other factors make it justifiable. These factors, for the most part, do not exist at the Quonset Point Facility because of the ability to plug in leads and wire feeders to station loaded power supplies, and the generally*

better accessibility for welding afforded at the earlier states of construction. At the Groton shipyard, where nearly all hangers are currently welded using SMA, switching to 0.035 inch diameter PGMAW with an easily moveable machine with a light-weight, small torch, is very beneficial.)

- Several welders thought the machine was too heavy. *(At the present time, the Ultralight is the lightest package that can be assembled that will output the power necessary for pulse GMA welding with 0.035 inch diameter electrode with the arc characteristics and duty cycle required for quality shipyard welding. The Ultralight represents a very significant leap in power to size/weight efficiency over contemporary welding equipment.)*

Overall, the Ultralight system was liked by the welders. After using the system for several days, many requested the Ultralight for other jobs. Most of the negative comments generated had to do with the original light-weight PGMA torch, and lack of experience with the new equipment and the small wire size.

Additional Discussion Concerning the Original Ultralight GMA Torch and SMA Stinger (Groton and Quonset Point)

Most of the negative comments regarding the Ultralight system involved the original prototype Ultralight GMA torch (Figure 4). Specifically, the welders did not like the style or location of the contactor switch (toggle switch in rather large housing mounted on top of the torch handle). The welders preferred a more conventional style switch, typically a momentary contact lever style switch nearly flush to the torch handle. (Although no specific complaints were received about the same design switch on the SMA stinger, it is recognized that the switch design is not desirable and needs to be changed.) The GMA torch also provided less than ideal puddle visibility and accessibility since tapered gas cups were not available, and the length of the flex-neck was typically too long. Due to the design of the existing torch body, it would probably not be possible to redesign the torch to accommodate a lever-style switch. As a result, an effort was undertaken in conjunction with ABCO Welding Supply, Waterford, CT, to develop an improved GMA torch or torches, and possibly apply improvements to the contactor switch to the SMA stinger as well.

<u>New Prototype Ultralight GMA Torches</u>

Two new prototype GMA torches were developed. As shown in Figures 7 and 8, one torch, based on a Lincoln Electric model, had a short, fixed goose-neck. The other torch, based on a Tweco model, had a short flexible neck. Both featured industry-typical, nearly flush mounted contactor switches, were light weight, and shared identical front-end parts (contact tips, gas cups, gas diffusers). Figure 9 shows the Lincoln-based torch next to the standard OXO 200A torch. The smaller size (including the conduit size) of the Lincoln-based torch is apparent. The two new prototype torches are both considerably lighter in weight then the standard OXO torch. Both prototype troches were judged to be very comfortable in the welder's hand. Electric Boat weld tested both torches in conjunction with a standard OXO AP20. As shown in Table VIII, for each of three wire feed speeds, the combination of trim (Vset) and arc control settings previously documented as optimum with the OXO torch were used. In all cases, all three guns performed nearly identically with

respect to measured amps and volts, and also in arc and puddle appearance. Therefore, the new prototype torches were judged to be compatible with the existing Electric Boat EB-200 MP welding procedures and thus suitable for shipyard welding. Multiple torch sets were procured and put into production. The new GMA torches, with their light weight, ease of manipulation, and comfort in the welder's hand, were well received and performed excellently. No negative comments were made by the users. These torches will become part of the production model EB-200 MP Ultralight welding systems that EB will procure. It is anticipated that by the time EB is ready to procure production systems, a redesigned SMA stinger incorporating an improved contactor switch on the torch handle will also be developed, tested, and approved by the EB Welding and Welding Engineering Departments.

Figure 7: Lincoln-Based Ultralight Torch (fixed goose neck)

Figure 8: Tweco-Based Ultralight Torch (flexible neck)

<u>Table VIII</u> – Comparison of New Ultralight GMA Torches to Standard OXO AP-20
EB-200 MP Prototype - Vertical Position Bead on Plate Welds
0.035" dia. ESAB MIL-100S-1, Program Mode 2

	OXO AP20 Torch (Fixed Goose-Neck)			**Lincoln-Based Torch (Fixed Goose-Neck)**			**Tweco-Based Torch (Flex-Neck)**		
WFS (ipm)	180	220	260	180	220	260	180	220	260
Vset	18.9	20.0	20.4	18.9	20.0	20.4	18.9	20.0	20.4
Arc Control	108	121	136	108	121	136	108	121	136
Current (A)	80-85	95-100	105-110	80-85	95-100	100-105	80-85	95-100	105-110
Voltage (V)	18.5	19.4	19.7	18.5	19.4	19.9	18.8	19.4	19.8

Figure 9: Size Comparison Between Lincoln-Based Ultralight Torch (Bottom) and Standard 200A OXO AP20 Torch (Top)

Estimate of Production Cost Savings With the EB-200 MP Ultralight Welding System

Calculating cost savings with the Ultralight welding system is by no means a trivial matter due to the many cost drivers that determine the cost of welding attachments and hangers. With the Ultralight equipment, the potential cost savings are attributable to many factors, including a change in process to pulse GMA from SMA, the portability of the equipment, a potential reduction in cleanup in the work area, elimination of the need to drag SMA leads on and off the boat, and enhanced accessibility allowing some hangers or portions of hangers formally welded using SMA to now be welded using PGMA. Additional cost savings can also be realized through an intangible (and largely immeasurable) factor: If a given job can be accomplished using an easier, less labor intensive method, the worker will have a better attitude, which usually results in greater throughput.

At the present time, the Electric Boat Groton shipyard and the Quonset Point Facility are not configured to make use of the Ultralight equipment as they will be when the equipment is ultimately purchased in quantity. This principally includes not having the proper primary power or primary power connection points in the areas needed. This effects how the small number of Alpha (evaluation) Ultralight machines have been used up to now, ultimately effecting many of the potential time savings benefits of the Ultralight (i.e., time to setup and hook up to the electrical distribution grid). It is noted that when Ultralight machines are purchased by Electric Boat, the investment will then be made to provide the proper electrical connections at the various production locations.

The Ultralight system was originally envisioned to be of primary interest to the Groton shipyard where final assembly is performed. At that stage of construction, many space restrictions are present in way of hanger installation welds, welding equipment may be located relatively far away from the work area, with long lead runs, and welding leads may

need to be cleared out of an area relatively frequently for various reasons. Additionally, moving traditional bulky and heavy power supplies and wire feeders through nearly completed compartments is difficult. As a result, SMA is the predominant welding process used for hanger welds in the Groton shipyard. In the Quonset Point Facility, much of the fabrication occurs with better accessibility for hanger and attachment welding, welding equipment is in-place close to the work area for an extended period of time, and most welders who are qualified for GMA are not qualified for SMA. As a result, PGMA is the predominate welding process for hanger and attachment welds. As such, the original cost savings estimate in Reference [2] was based solely on projected Electric Boat Groton shipyard work. The new cost savings estimate developed under this project, based on Electric Boat experience with the Ultralight welding system, is based on implementation of the system at both the Groton shipyard and the Quonset Point Facility.

Reference [2] contained a cost savings estimate in the Electric Boat Groton shipyard for the five year period following implementation of the Ultralight welding system. This estimate assumed a certain number of hanger and nonstructural bulkhead welds based on the forecast construction work and the breakdown of work performed between the Groton shipyard and the Quonset Point Facility. Based on this, the number of weld lead clusters (and weld lead repairs) needed for SMA welding, and the number of trade debris cleanups, SMA arc strike repairs, and equipment setups were estimated. Labor savings per operation were estimated based on the Electric Boat perception of how the Ultralight system would function. From this, the total number of hours saved per years was estimated. Potential savings in material were also estimated.

A calculation of the cost savings per year based on the Electric Boat production experience with the five Alpha test machines was made. The same labor operations and material categories originally considered in the pre-project award cost estimate were used. The assumptions for the new estimate were:

- The Ultralight system will be available in the required numbers and with the required shipyard infrastructure (power attachment points available where needed, etc.).
- Welders will have the ability to perform the plugging in / unplugging of the equipment (not currently allowed in the Groton shipyard with the normal 460V 3-phase welding equipment).
- Groton shipyard welders using the Ultralight will be qualified in both the pulse GMA and SMA processes (allowing for the same welder to use two different welding processes, if necessary, for welding a hanger). This is normally the case for the Groton shipyard, but not for the Quonset Point Facility, where it is assumed that welders will not generally be qualified to use both processes.
- Welders will be allowed to have with them both solid GMA electrode and SMA rod of the same alloy type (i.e., MIL-70S-3 solid electrode and MIL-7018-M SMA electrode). (This is not currently allowed except for a very narrow class of welds in a particular fabrication area.)

Tables IX and X detail the projected labor savings per year in the Groton shipyard and the Quonset Point Facility, respectively. Table XI shows the projected materials savings per

year at the Groton shipyard. In Table IX, the estimated labor savings per item did not change between 2003 and 2007, just the number of items in some of the categories. The number of items changed principally as a result a redistribution in the work balance between the two Electric Boat facilities, with more hanger work being shifted to the Quonset Point Facility. This work shift is also reflected in the material savings estimated in Table XI. Much of the Groton shipyard labor and material savings are directly associated with the ability to use PGMA welding in place of SMA welding with the Ultralight system. The reduction in the number of SMA lead removals, repairs, and forming of the SMA lead clusters alone accounts for 42% of the estimated yearly labor cost savings. Over $100,000 per year is estimated to be saved as a direct result of eliminating many of the SMA leads. In the Quonset Point Facility, the labor savings arise from the ability to switch from total or partial use of SMA for some hanger welds to 100% PGMA, principally since the Ultralight torch allows superior accessibility compared to other standard GMA torches used with conventional power supplies. There are no labor savings in SMA lead reduction or materials savings for the Quonset Point Facility as was the case for the Groton shipyard as a result of the overall lack of use of SMA for this type of work to begin with, and the availability of station loaded machines.

Assuming a labor rate of $60 per hour, the projected labor savings amount to $283,000 per year for the Groton shipyard and $11,000 per year for the Quonset Point Facility. The total projected savings for both facilities, including the material savings shown in Table XI, is therefore $398,000 per year.

The first year cost savings will be reduced by approximately $64,000 through the purchase of approximately 16 Ultralight welding systems, including associated welding torches, spare parts, and cables. It is anticipated that 10 units would be purchased in the second year (approximately $40,000). Training costs to be incurred in the first year are not expected to exceed a total of $15,000. The installation of 220-volt single phase service will principally be met by Electric Boat's planned Land Level Facilities upgrade (Groton) and will not be driven by the acquisition of Ultralight systems. The Groton shipyard does anticipate the need to purchase two additional e-Cart™-Jr. power distribution devices (approximately $7,000) to bridge the gap between initial implementation the Ultralight systems and completion of the facilities upgrade. The Quonset Point Facility has 220-volt single phase service available in some areas. No additional costs for maintenance are anticipated; shops and equipment in the shipyard used to maintain current welding systems can support the Ultralight systems.

Net first year savings are therefore estimated to be $312,000 with savings on the order of $358,000 in the second year and $398,000 per year thereafter.

Table IX – Labor Savings Estimates for Five Year Period After Ultralight Welding System Implementation, Electric Boat Groton Shipyard Only

Labor Operation	Number per Year		Labor Savings per Operation (hours)	Saving per Year (hours)	
	Dec. 2003 Estimate [2]	July 2007 Estimate		Dec. 2003 Estimate [2]	July 2007 Estimate
Pipe Hanger Welds	2,000	1,340	0.5	1,000	670
Electrical Hanger Welds	561	376	0.5	280	188
Equipment Setups for Nonstructural Bulkhead Welds	583	391	0.5	292	196
Removals of SMA Weld Lead Clusters of 15 Leads Each	10	10	120	1,200	1,200
Forming of SMA Weld Lead Clusters	15	15	32	480	480
Trade Debris Cleanups	1,280	960	0.5	640	480
SMA Weld Lead Repairs	312	312	1	312	312
SMA Arc Strike Repairs	88	88	5	440	440
Equipment Control Center Setups	100	75	10	1,000	750
Total				**5,644**	**4,716**

Table X – Labor Savings Estimates for Five Year Period After Ultralight Welding System Implementation, Quonset Point Facility Only

Hanger Installation Variation	No. of Hangers per Year	Labor Savings per Hanger (hours)	Total Labor Savings per Year (hours)
Hangers with poor accessibility currently welded using SMAW that can be welded using PGMAW with the EB-200 MP and Ultralight torch	40	1.5	60
Hangers currently welded using combination of PGMAW and SMAW that can be completely welded using PGMAW with the EB-200 MP and Ultralight torch	60	2.0	120
Total			**180**

Table XI – Material Savings Estimates for Five Year Period After Ultralight Welding System Implementation, Electric Boat Groton Shipyard Only

Purchased Item	Cost Per Item ($)	Reduction in No. of Items per Year		Savings per Year ($)	
		Dec. 2003 Estimate [2]	July 2007 Estimate	Dec. 2003 Estimate [2]	July 2007 Estimate
100 foot SMA Welding Leads	220	186	125	40,920	27,500
SMA Power Distribution Systems	12,000	6	6	72,000	72,000
SMA Weld Lead Repair Material	20	312	209	6,240	4,180
Total				**119,160**	**103,680**

CONCLUSIONS

The goals of this program were met. Specifically, a 40 pound welding system consisting of a portable inverter power supply with integral wire feeder was developed that:

- Was hand portable by a single man.
- Produced excellent arc and puddle characteristics, comparable to those obtained using standard PGMAW equipment currently in use at Electric Boat.
- Had PGMA and SMA duty cycles suitable for hanger and other light welding tasks.
- Used 10 to 12 pound spools of 0.035 in. diameter electrode for PGMAW. 2 pound spools are also supported.
- Operated using 220-volt single phase power.
- Used pulse welding current waveforms suitable for 0.035 in. diameter MIL-100S-1 electrode that provided legacy calculated cooling rate versus weld metal yield strength performance.
- Was SMAW capable to support welding where PGMAW is not possible or recommended.
- Could be easily and quickly changed over from SMA to PGMA, and back.
- Was programmable and therefore able to meet the requirements of various shipyards.
- Used compact, light-weight GMAW torches to maximize the number of welds where use of the new welding system would be advantageous.

ACCOMPISHMENTS

The following major accomplishments were attained under this program:

- Successful development of power supply and wire feeder technology to produce a 40 pound man-portable welding system capable of high quality all-position pulse gas metal arc and shielded metal arc welding of naval ship structures.
- Safety improvement attained by using 220V single-phase power in place of 460V 3-phase power.
- Successful development of two light-weight gas metal arc welding torches allowing improved accessibility to maximize use of gas metal arc welding in place of shielded metal arc welding.
- Successful approach/equipment developed to allow quick changeover between the shielded metal arc and gas metal arc processes, allowing use of a single machine to do all hanger welding with a minimum of effort.
- The developed welding system is capable of reducing welding costs for applications where it is advantageous to use a small, man-portable machine and pulse GMA welding can be used in place of SMA welding.

REFERENCES

1. Subcontract Agreement between Advanced Technology Institute and Electric Boat Corporation, Subcontract No. 2004-388, placed under Contract N00014-03-C-013, 1 April 2004.
2. Technical proposal submitted by Electric Boat Corporation pursuant to RFP Request No. CNST-CAK1029-41717, Ultralight Gas Metal Arc Welding Project, dated December 18, 2003.
3. MS Report – “Ultra-light Inverter”, Lincoln Electric Project Number 5024463, Document Revision A.01.